waveguides, etc. can be employed used in the combiners **32** and distributors **34**. The multi-port devices can be used alone, or in various combinations of filters, such tunable or fixed, high, low, or band pass or band stop, transmissive or reflective filters, such as Bragg gratings, Fabry-Perot, Mach-Zehnder, and dichroic filters, etc. Furthermore, one or more serial or parallel stages incorporating various multi-port device and filter combinations can be used in the combiners **32** and distributors **34** to multiplex, demultiplex, and multi-cast signal wavelengths λ_i in the optical systems **10**.

[0054] **FIG. 3** illustrates a double pass Mach Zehnder ("DPMZ") filter **40**, which can be deployed in the system **10** of the present invention. The double pass Mach-Zehnder filter **40** includes at least first and second optical coupling sections, e.g., $\mathbf{42}_1$ and $\mathbf{42}_2$, interconnected by first and second ends of at least two optical communication paths, or Mach-Zehnder legs, e.g., $\mathbf{44}_1$ and $\mathbf{44}_2$, which together defines a Mach-Zehnder interferometer. The first coupling section $\mathbf{42}_1$ includes one or more input/output (I/O) ports, e.g., $\mathbf{46}_1$, and $\mathbf{46}_2$, and the second coupling section $\mathbf{42}_2$ includes first and second output/input (O/I) ports, $\mathbf{48}_1$ and $\mathbf{48}_2$, respectively.

[0055] The double pass Mach-Zehnder filter **40** can be constructed from various waveguide material, such as described with respect to the transmission media **16**. For example, the double pass Mach-Zehnder filter **40** can be a fiber-based or planar device and include free space components as will be described.

[0056] As further shown in **FIG. 3**, the output/input ports, $\mathbf{48}_1$ and $\mathbf{48}_2$, are connected optically, such that optical energy, or signals, exiting at least one of the O/I ports **48** from the Mach-Zehnder legs **44** will be provided as input into the other O/I port. For example, signals exiting the second coupling section $\mathbf{42}_2$ from the Mach-Zehnder legs **44** via the first O/I port $\mathbf{48}_1$ will reenter the second coupling section $\mathbf{42}_2$ via the second O/I port $\mathbf{48}_2$. The converse occurs for those signals exiting the Mach-Zehnder legs **44** via second O/I port $\mathbf{48}_2$.

[0057] The Mach-Zehnder legs, $\mathbf{44}_1$ and $\mathbf{44}_2$, are designed to introduce an effective path length difference, or mismatch, between the first and second coupling section, $\mathbf{42}_1$ and $\mathbf{42}_2$. The effective path length difference can be a physical difference in that one path, e.g., fiber length, is longer than the other path. Alternatively, the path length difference can be induced by varying the waveguide properties of the communication paths, such as refractive index, temperature, strain, electric and magnetic fields, etc. to induce an effective path length difference.

[0058] The mismatch produces constructive and/or destructive interference of optical energy introduced into the coupling sections **42** as a periodic function of wavelength. The mismatch defines a filter function based on the wavelength periodicity, wherein the transmission T_{SP} through the Mach-Zehnder interferometer and the frequency period P_v can be described by the equation:

$$T_{SP}=\cos^2(\alpha\Delta L/2),\text{ and}$$

[0059] $P_v=c/(n\Delta L)$, respectively, where

[0060] α=propagation constant through the transmission media **16**;

[0061] ΔL=path length difference between the Mach-Zehnder legs, $\mathbf{44}_1$ and $\mathbf{44}_2$;

[0062] c=speed of light; and,

[0063] n=refractive index of the transmission media **16** comprising the Mach-Zehnder legs **44**.

[0064] In the present invention, optical energy is double passed through the Mach-Zehnder interferometer, such that the effective filter function T_{DP} is the square of the filter function T_{SP} for a single pass through the Mach-Zehnder interferometer or

$$T_{DP}=\cos^4(\alpha\Delta L/2)$$

[0065] In **FIG. 3** embodiments, optical energy introduced into the double pass Mach-Zehnder **40** via the first input/output $\mathbf{46}_1$ port will be output from the first output/input port $\mathbf{48}_1$ according to the function T_{SP}. The output from the second input/output port $\mathbf{48}_2$ is according to the complementary function $1-T_{SP}$.

[0066] If the optical energy exiting the output/input port **48** is introduced back into the other output/input port **48** without alteration, the optical energy will exit the second input/output $\mathbf{46}_2$ port substantially as it entered the first input/output $\mathbf{46}_1$ port. The separation followed by recombination of the optical energy as it passes through the double pass Mach-Zehnder filter allows various filtering and/or monitoring functions to be performed, as will be described further. For example, monitoring equipment, such as photodiodes, optical spectrum analyzers, etc., can be deployed between the output/input ports **48** in the **FIG. 3** embodiment. The monitoring equipment can monitor the separated optical energy, thereby providing finer granularity during monitoring and decreasing monitoring equipment specifications without disrupting the overall signal.

[0067] In various embodiments, isolators, circulators, and other wavelength or non-wavelength selective isolation and/or reflective devices can be used to provide only one signal output from the output/input ports **48** as a second pass input to the output/input ports **48**. In this manner, wavelengths transmitted to one of the output/input ports can be selectively filtered by the filter **40**.

[0068] **FIGS. 4*a-b*** show double pass Mach-Zehnder embodiments, in which an isolator **50** is provided to prevent optical energy exiting the second output/input port $\mathbf{48}_2$ from entering the first output/input port $\mathbf{48}_1$ (**FIG. 4*a***). The opposite occurring in **FIG. 4*b*** embodiments. Thus, in **FIG. 4*a***, only optical energy exiting first output/input port $\mathbf{48}_1$ will exit the double pass Mach-Zehnder filter **40** via the second input/output port $\mathbf{46}_2$. If the optical energy enters the double pass Mach-Zehnder filter **40** via the first input/output port $\mathbf{46}_1$, the optical energy will be filtered with the transmitted energy and the will exit the double pass Mach-Zehnder filter **40** via the second input/output port $\mathbf{46}_2$. The opposite being true for optical energy entering the second input/output port $\mathbf{46}_2$.

[0069] **FIG. 5** shows a double pass Mach-Zehnder filter function along with its corresponding single pass filter function for embodiments such as those shown in **FIG. 4*b***. The double pass Mach-Zehnder filter provides a filter function, in which the transmission is a much stronger function of frequency than the single pass filter. The filter function of the double pass Mach-Zehnder filter increases it effectiveness as a filter, because the slope of the transmission function provides for increased isolation between the peak